The differences in knee muscle activities between healthy male and female elderlies during walking: Pilot study

Nusreena Hohsoh[1], Thanita Sanghan[1], Desmond Y.R. Chong[2] and Surapong Chatpun[*1, 3]

[1]Department of Biomedical Sciences and Biomedical Engineering, Faculty of Medicine, Prince of Songkla University, Hatyai 90110, Songkhla, Thailand
[2]Engineering Cluster, Singapore Institute of Technology, Singapore 138683, Singapore
[3]Institute of Biomedical Engineering, Faculty of Medicine, Prince of Songkla University, Hatyai 90110, Songkhla, Thailand
[*]Corresponding author, E-mail: surapong.c@psu.ac.th

Abstract

Aging-related loss of muscle strength with a cumulative loss of muscle mass results in functional impairment and risk of falling. Moreover, knee extensor muscle weakness is associated with a higher risk of knee osteoarthritis in both females and males. The variability of electromyography (EMG) signals in males and females varied in each gait phase. The characteristics of knee EMG during a gait cycle in female and male elderlies have not been clarified clearly. The purpose of this study was to determine the differences in knee muscle between female and male elderlies during overground walking. Five healthy females and five healthy males with ages over 60 years old were recruited for this study. The participants performed 3 trials of walking back and forth at a comfortable gait speed on a 10-meter walkway. The surface EMG signals were recorded on two muscles in each leg, comprising the rectus femoris (RF), and the long head of biceps femoris (BF) during the entire gait cycle. The knee muscle activity was investigated considering the right and left sides together in the root mean square (RMS) and waveform length (WL). The asymmetry index (ASI) of the knee muscle between the right and left sides in female and male elderlies was evaluated in the mean absolute value (MAV) and log detector (LOG). The characteristics of EMG signals were evaluated in the stance and swing phases of the gait cycle. This study found that RMS and WL of RF and BF were not different between elderly females and males during the entire gait cycle. Asymmetry index of MAV of BF (male 47.61 ± 27.71 vs. female 16.45 ± 11.68) and LOG of RF (male 10.07 ± 1.86 vs. female 4.54 ± 4.71) and BF (male 14.80 ± 8.77 vs. female 5.04 ± 3.31) in males was higher than females during a swing phase. This pilot study provides useful information to characterize knee muscle activity in elderlies. The knee muscle activities between female and male elderlies were not much different in both gait phases. Interestingly, the asymmetry between limbs of the knee muscles during the swing phase in elderly males was higher than in elderly females although they are healthy.

Keywords*: *Electromyography, Asymmetry index, Gender, Knee muscle, Gait cycle

1. Introduction

The world's aging population increases dramatically in recent decades. Many countries are currently transitioning to an aging society which is one of the mega trends in the world. Approximately 450 million individuals or 60% of the elderly population in the world live in developing countries. According to projections, this proportion will rise to 71% by 2030 (Zubiashvili, 2021). The ability of physical health becomes less efficient as getting older (Iamtrakul & Chayphong, 2021). Aging people lose 1–1.5% of muscle strength each year, with a cumulative loss of 30–50% of muscle mass by the age of 80 years. This leads to increasing weakness, the risk of falling, and functional impairment. In addition, aging-related changes in the subchondral bone and joint cartilage result in an increased risk of osteoarthritis (Grote et al., 2019). Osteoarthritis is the most prevalent type of arthritis. It causes pain and functional limitations due to inflammation and severe structural changes in the joints. The global prevalence of knee osteoarthritis has shown that symptomatic knee osteoarthritis is estimated to be 3.8 % (Oshima et al., 2019).

Published online: Copyright © 2016-2022 Rangsit University

It was reported that the weakness of the quadriceps muscle was associated with a higher risk of knee osteoarthritis in both females and males compared with individuals who have the highest value of quadriceps strength (Takagi et al., 2018). Patients with knee osteoarthritis have a higher rate of deviations in step length, step width, and double support time, as well as movement stability (Matsumoto et al., 2015). The Rectus femoris, a quadriceps muscle, is the main muscle that controls a knee flexion and prohibits a knee-buckling in the stance phase it also controls a knee extension as well as stabilizes the limb before weight-bearing in the swing phase of the gait cycle. In addition, the knee flexor muscle i.e., the biceps femoris is activated to generate knee flexion in the swing phase (Webster, & Darter, 2019).

The muscle activity is usually assessed by surface electromyography (sEMG). It is a non-invasive measurement to evaluate neuromuscular activity which relates to the activation of muscles. It is a challenging assessment to analyze the dynamic muscle contraction during gait. The characteristics of the EMG signals during the gait cycle are displayed from the value of motor unit action potential recruitment in consonance with the character of the gait phases, such as muscle burst timing and intensity of muscle contraction. The on-off timing of each muscle function relates to the limb movement in each gait phase (Papagiannis et al., 2019). To interpret the voluntary muscle contraction based on the EMG signals, some EMG features must be extracted to obtain the effectiveness of EMG (Fang et al., 2020).

Previous studies have investigated the muscle activity using EMG signals as follow: Marques et al., (2016) studied the differences of EMG signal on lower limb muscles (gluteus maximus, rectus femoris, biceps femoris, lateral gastrocnemius, and tibialis anterior) activity in the stance phase of gait between younger and elderly females. They found that the rectus femoris muscle in the initial stance phase in elderly females was lower than in younger females. Besides, Szpala (2019) has reported the EMG amplitude on rectus femoris, vastus lateralis, vastus medialis, and biceps femoris muscles in elderly females was lower than in younger females. In addition, both elderly and younger females were symmetrical in EMG amplitude between the right and left sides. Bailey et al., (2018) investigated the EMG signal in lower limb muscles (rectus femoris, tibialis anterior, and lateral gastrocnemius) during walking. They studied the correlation between age and gender on lower limb muscle activity and found that the older age was strongly associated with lower rectus femoris and increased lateral gastrocnemius with a phenomenon toward lower tibialis anterior amplitude during the gait cycle. As for the differences in muscle activity between males and females, the muscle activity showed higher activation of rectus femoris in males and higher activation of lateral gastrocnemius in females. Furthermore, aging has a gender-dependent effect on the variability of EMG signals within the gait cycle. In the stance phase, the variability of EMG signal in males reduced at the loading response while in females the variability of EMG signal was high at the terminal stance (Bailey et al., 2018).

According to the previous studies, knee muscle weakness was associated with a higher risk of knee osteoarthritis in both females and males. The variability of EMG signals was varied between female and male elderlies in each phase of the gait cycle. This study hypothesized that the knee muscle activity in male elderlies is higher than that in female elderlies in both stance and swing phases of the gait cycle.

2. Objectives

1) To determine the differences in EMG signals on knee muscles between female and male elderlies during stance and swing phases

2) To determine an asymmetry index of the knee muscles activities between right and left sides in individual female and male elderlies during stance and swing phases

3. Materials and Methods

3.1 Study design and subjects

This study was an observational case-control study. We recruited 10 healthy elderly volunteers: 5 males (age: 64.83 ± 2.78 years) and 5 females (age: 66.55 ± 3.27 years). All participants were able to continue the daily activity for at least 30 minutes without angina chest pain or falling. The exclusion criteria were a history of musculoskeletal problems (i.e., acute low back pain, knee osteoarthritis, lower limb

Published online: Copyright © 2016-2022 Rangsit University

arthritis), previous history of major falls, and a history of lower limb arthroplasty. The experimental protocol was approved by the Human Research Ethics Committee of the Faculty of Medicine, Prince of Songkla University, Thailand (REC.64-386-25-2).

3.2 Data collection methodology

3.2.1 Demographics and physical assessment

Participants' demographic data and physical assessment were examined by a physical therapist. The demographic recorded data were age, sex, body mass index (BMI), medical history, current medication, and previous history (i.e., musculoskeletal problems, major falls, lower limb arthroplasty). The basic vital signs, i.e., blood pressure, heart rate, respiratory rate, and body temperature were recorded. Cognitive assessment was measured using Montreal cognitive assessment. The fear of falling was assessed using the falls efficacy scale international assessment. The ability to walk 10 meters was determined using the 10-meter walk test. The subjects should walk at a self-selected speed of 10 meters. Muscle power of the lower limb muscles was investigated using manual muscle testing.

3.2.2 Experimental setup and EMG measurements

EMG signals were recorded from knee muscles on right and left sides: the rectus femoris (RF), and the long head of biceps femoris (BF). Four channels of the EMG (Zerowire, Aurion, Italy) and three force plates (AccuGait Force Plate, AMTI, USA) of the Vicon system (Vicon Motion System Ltd., Oxford, England) were used to record the EMG signals and ground reaction force respectively with a sampling rate of 1,000 Hz. The gait cycle in stance phase (ST), and swing phase (SW) were recorded by the Pedar-X System (Novel, Germany) at 100 Hz. Two video cameras were used to capture the movement behaviors during walking.

The bipolar surface electrodes, Ag/Cl (Ambu® surface electrodes, Denmark), with electrode size 34×40 mm circular conductive area were placed on the specific motor point locations for each muscle as presented in Figure 1. The Rectus femoris locates halfway through the anterior thigh approximately ½ of the distance between the anterior-superior iliac spine and the superior border of the patella and the long head of the bicep femoris locates at the middle of the posterior thigh approximately ½ of the distance between ischial tuberosity and apex of the fibular. The skin area of both knee muscles was cleaned with an alcohol pad to decrease skin impedance and improve the quality of EMG signals.

The participants of both groups followed the same protocol by conducting 3 trials of walking back and forth at a comfortable gait speed on a 10-meters walkway for 2 rounds. Then, participants took a rest for 5 minutes between the trials and were assessed for their vital signs during resting.

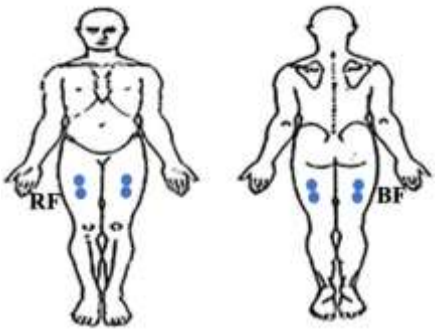


Figure 1 The electrodes' placement for rectus femoris (RF) and long head of biceps femoris (BF) (Rhon, Lentz, & George, 2017).

Published online: Copyright © 2016-2022 Rangsit University

3.3 Data processing and analysis

The raw EMG signals of both groups were processed using MATLAB software (MATLAB R2021b, MathWorks, USA). The raw EMG signals were filtered with a bandpass frequency between 30 and 450 Hz, and the electrical line noise was removed using a notch filter at 50 Hz. The knee muscle activity was evaluated in a stance (ST), and swing (SW) phases. The muscle activity was evaluated across the gait phase for 5 consecutive gait cycles.

The knee muscle activity was determined using time-domain features for the following four features: the root mean square (RMS), mean absolute value (MAV), waveform length (WL), and log detector (LOG) (Phinyomark, Phukpattaranont, & Limsakul, 2012). The RMS and WL were analyzed concerning the right and left sides together and normalized with the mean of EMG amplitudes across the gait phases for 5 consecutive gait cycles to compare the differences between females and males. The MAV and LOG were analyzed considering the right and left sides separately in each subject for 5 consecutive gait cycles to measure an asymmetry index (ASI) of MAV and LOG EMG by the equation (1) as follows:

$$\text{ASI}\ (\%) = \frac{|\,2\times \text{EMG}_L - EMG_R|}{|\text{EMG}_L + EMG_R|} \times\ 100\% \qquad (1)$$

Where $EMG_{(L)}$ is the mean absolute value (MAV), and log detector (LOG) values of the muscle on the left knee and $EMG_{©}$ is the mean absolute value (MAV), and log detector (LOG) values of the muscle on the right knee.

3.4 Statistical analysis

All statistical analysis in this study was determined using Prism 9.0 (GraphPad, USA). An unpaired t-test was used to compare the differences between females and males. A paired t-test was done in a case between the right and left sides. The level of statistical significance was considered when $p < 0.05$.

4. Results and Discussion

This study investigated the knee muscle activity of the RF, and BF and the asymmetry index (ASI) of knee muscles between the right and left sides during the stance and swing phases, by comparing the performance of healthy females with that of healthy males. The demographic data of the subjects are presented in Table 1. There is no statistically significant difference of age (p = 0.3959), BMI (p = 0.7027), walking speed (p = 0.4651), stance time (p = 0.7715), and swing time (p = 0.9734) between female and male elderlies. It showed that female elderlies spent stance time and swing time like male elderlies spent. The representative examples of the filtered EMG signals from RF and BF of a healthy female and healthy male are shown in Figure 2. The EMG signals demonstrate that both RF and BF were activated at the beginning of the stance phase and the late state of the swing phase in both males and females. The RMS, WL, and the ASI of MAV and LOG of RF and BF during the stance and swing phases were examined to investigate the differences in knee muscle activities.

Table 1 Demographic of female and male elderlies

Variables	Female (n = 5)	Male (n = 5)
Age (years)	64.83 ± 2.78	66.55 ± 3.27
BMI (kg/m^2)	22.51 ± 3.80	21.71 ± 2.40
Walking speed (m/s)	1.03 ± 0.21	1.15 ± 0.29
Stance time (sec)	0.73 ± 0.04	0.74 ± 0.05
Swing time (sec)	0.44 ± 0.02	0.44 ± 0.03

Values are in the mean ± SD, Body mass index (BMI)

Published online: Copyright © 2016-2022 Rangsit University

The mean RMS and WL values of EMG signals of RF and BF in both groups are presented in Figure 3. There are no statistically significant differences between RMS and WL of the female and male elderlies in the stance and swing phases. However, the results of RMS and WL, in both stance phase and swing phase, show the trend that male elderlies have higher muscle activity than female elderlies.

These results are supported by Bailey and colleagues who revealed no difference in rectus femoris between female and male elderlies (Bailey et al., 2018). A study by Krishnan and Williams reported the patterns of hamstring (semitendinosus and biceps femoris) muscle activity were similar between males and females (Krishnan and Williams, 2009).

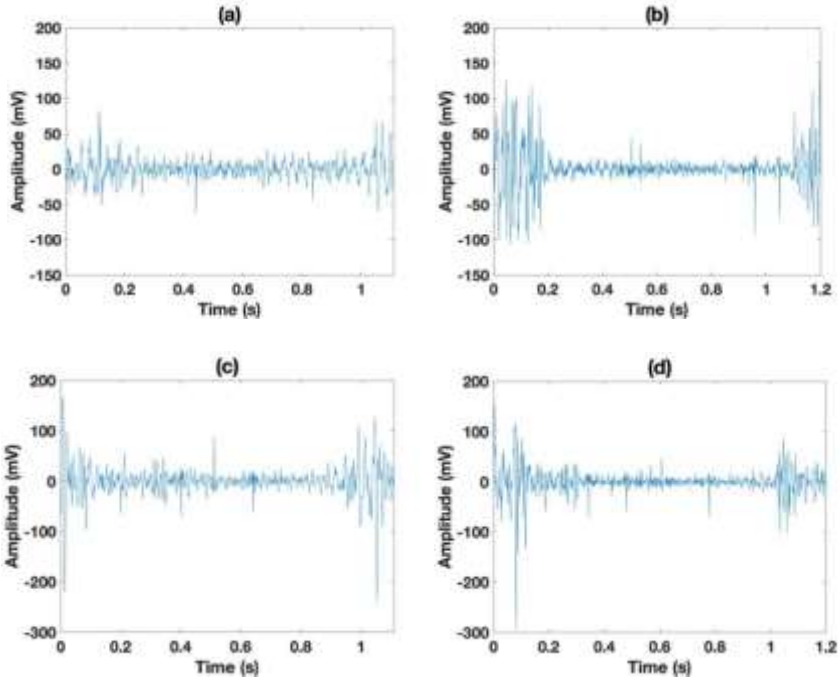
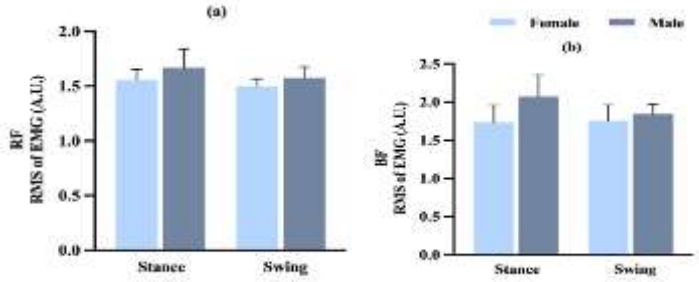


Figure 2 Examples of the filtered EMG signals during one gait cycle from (a) and (b) rectus femoris of female and male respectively, (c) and (d) long head of biceps femoris of female and male, respectively.



Published online: Copyright © 2016-2022 Rangsit University

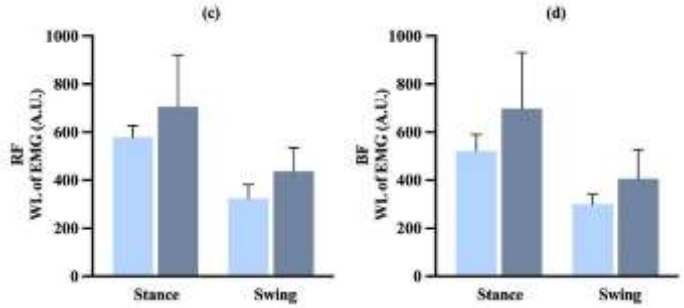


Figure 3 RMS and WL of knee muscle activity of the females and males during stance and swing phases for (a) RMS of the rectus femoris (RF), (b) RMS of the long head of biceps femoris (BF), (c) WL of the rectus femoris (RF), and (d) WL of the long head of biceps femoris (BF).

The ASI index of the MAV of RF in the stance and swing phases were no statistically significant difference between female and male elderlies (Table 2). The ASI index of the MAV of the BF during the swing phase in male elderlies was higher than female elderlies (p = 0.0492) but no statistically significant difference during the stance phase (Table 3).

Table 2 Mean absolute values (MAV) of EMG signals from individuals for right and left sides and the asymmetry indexes (ASI) of rectus femoris (RF) activity

Subjects	Stance phase						Swing phase					
	Female			Male			Female			Male		
	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)
1	15.40	10.98	33.50	17.11	13.66	22.42	11.97	11.29	5.78	16.91	13.69	21.01
2	12.04	14.58	19.08	16.90	16.90	0.00	14.12	12.45	12.54	7.32	8.85	18.92
3	11.07	10.32	7.01	13.23	16.63	22.75	9.27	9.74	4.85	8.55	10.67	21.98
4	9.65	10.09	4.55	10.51	10.73	2.06	15.76	11.38	32.27	8.80	7.00	22.77
5	14.74	16.14	9.10	17.67	15.64	12.19	8.97	8.81	1.72	14.96	10.85	31.81
Mean	12.58	12.42	14.65	15.09	14.71	11.88	12.02	10.74	11.43	11.31	10.21	23.30
SD	2.44	2.75	11.90	3.10	2.56	10.79	2.97	1.45	12.30	4.31	2.49	4.97

** $p < 0.05$ significantly different between female and male elderlies*

Table 3 Mean absolute values (MAV) of EMG signals from individuals for right and left sides and the asymmetry indexes (ASI) of the long head of biceps femoris (BF) activity

Subjects	Stance phase						Swing phase					
	Female			Male			Female			Male		
	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)
1	31.71	16.45	63.36	36.25	17.08	71.88	48.48	38.91	21.90	33.86	15.07	76.81
2	23.22	23.11	0.50	11.43	20.02	54.60	30.99	25.86	18.05	36.25	19.18	61.60
3	17.82	20.03	11.66	49.65	26.90	59.45	32.02	23.16	32.09	30.87	36.64	17.08
4	12.61	13.99	10.42	10.61	12.69	17.88	22.35	21.76	2.67	15.66	12.97	18.79
5	23.10	12.61	58.71	22.84	11.03	69.75	10.06	9.33	7.53	74.17	38.30	63.78
Mean	21.69	17.23	28.93	26.16	17.54	54.71	28.78	23.80	16.45	38.16	24.43	47.61*
SD	7.11	4.32	29.67	16.76	6.32	21.79	14.10	10.57	11.68	21.67	12.12	27.71

** $p < 0.05$ significantly different between female and male elderlies*

Published online: Copyright © 2016-2022 Rangsit University

The ASI of the LOG of the RF during the swing phase in male elderlies is significantly higher than in female elderlies (p = 0.0406) but there is no statistically significant difference in the stance phase (Table 4). Likewise, the ASI of the LOG of the BF during the swing phase in male elderlies was higher than in female elderlies in the swing phase (p = 0.0483), but no statistically significant difference was not found in the stance phase (Table 5).

A previous study reported that healthy young females demonstrated higher quadriceps activity than males during treadmill walking gait which means gender can cause the difference in muscle activity (Smith et al., 2021). In contrast, our study found that the male elderlies had higher asymmetry indexes of RF and BF activity during the swing phase in comparison to the female elderlies. Furthermore, the EMG signals in female elderlies were symmetric in the knee muscles (vastus lateralis, vastus medialis, rectus femoris, and biceps femoris) as well as in younger women (Szpala, 2019). Furthermore, the decrease of peak torque and relative force in knee flexors is a crucial cause that leads to falling in the elderly. Asymmetry in the male group can result from unequal physical responses, such as the use of the dominant limb more than another limb (LaRoche et al., 2017). Moreover, asymmetry in knee extensor muscle strength may be another risk factor for falls during walking in elderly people (Chon et al., 2018). The BF is the most common muscle of hamstring strain injury, and males have a larger risk than females. Hamstring strain injury most occurs during the late stage during the swing phase, when the BF is contracting eccentrically (Behan et al., 2018). Also, males are less flexible of muscle than females, but they have more muscular strength and can compensate for their lack of flexibility with their muscular strength. Moreover, asymmetry in the lower extremities is related to gait deficits and falls (Chon et al., 2018). Hence, it is essential for evaluating asymmetry and supporting the interventions to prevent falls, which would be beneficial in ambulatory elderly people.

Our study provides information on asymmetry indexes in the subphase of the gait cycle in elderlies. However, this study has several limitations. First, the number of participants should be increased to represent the elderly population. Second, this study has investigated only the rectus femoris and the long head of the biceps femoris, other muscles that surround the knee, the ankle, and the hip should be investigated.

Table 4 Log detector (LOG) of EMG signals from individuals for right and left sides and the asymmetry indexes (ASI) of rectus femoris (RF) activity

	Stance phase						**Swing phase**					
Subjects	**Female**			**Male**			**Female**			**Male**		
	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)
1	2.73	2.40	13.18	2.84	2.61	8.26	2.48	2.42	2.36	2.83	2.62	7.75
2	2.49	2.68	7.41	2.82	2.82	0.00	2.65	2.52	4.86	1.99	2.18	9.10
3	2.40	2.33	2.96	2.58	2.81	8.47	2.23	2.27	2.15	2.15	2.37	9.78
4	2.27	2.31	1.99	2.35	2.37	0.87	2.76	2.76	12.55	2.17	1.95	11.10
5	2.69	2.78	3.32	2.87	2.74	4.34	2.19	2.18	0.79	2.70	2.38	12.61
Mean	2.52	2.50	5.77	2.69	2.67	4.39	2.46	2.37	4.54	2.37	2.30	10.07*
SD	0.19	0.21	4.63	0.22	0.19	3.97	0.25	0.14	4.71	0.37	0.25	1.86

** $p < 0.05$ significantly different between female and male elderlies*

Published online: Copyright © 2016-2022 Rangsit University

Table 5 Log detector (LOG) of EMG signals from individuals for right and left sides and the asymmetry indexes (ASI) of the long head of biceps femoris (BF) activity

Subjects	Stance phase						Swing phase					
	Female			Male			Female			Male		
	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)	Right (mV)	Left (mV)	ASI (%)
1	3.46	2.80	20.97	3.59	2.84	23.41	3.88	3.66	5.83	3.52	2.71	25.97
2	3.15	3.14	0.15	2.44	2.99	20.62	3.43	3.25	5.41	3.59	2.95	19.46
3	2.88	2.99	3.97	3.90	3.29	17.03	3.47	3.14	9.79	3.43	3.60	4.87
4	2.53	2.64	4.03	2.36	2.54	7.32	3.11	3.08	0.86	2.75	2.56	7.09
5	3.14	2.53	21.32	3.13	2.40	26.33	2.31	2.23	3.32	4.31	3.64	16.62
Mean	3.03	2.82	10.09	3.08	2.81	18.94	3.24	3.07	5.04	3.52	3.09	14.80*
SD	0.34	0.25	10.21	0.68	0.36	7.35	0.59	0.52	3.31	0.55	0.50	8.77

** $p < 0.05$ significantly different between female and male elderlies*

5. Conclusion

This pilot study revealed that knee muscle activity in elderly females and males was not much different in both stance and swing phases. However, asymmetry was found in the male elderlies in the rectus femoris and long head of biceps femoris only during the swing phase. Additional muscles on the other joints of the lower limb are necessary to investigate in further study to prevent a fall and perform a gait rehabilitation in the elderly.

6. Acknowledgements

This study was financially supported by the Faculty of Medicine, Prince of Songkla University, Thailand. We would like to thank all participants for their contribution to the study.

7. References

Bailey, C. A., Corona, F., Pilloni, G., Porta, M., Fastame, M. C., Hitchcott, P. K., Penna, M. P., Pau, M. & Côté, J. N. (2018). Sex-dependent and sex-independent muscle activation patterns in adult gait as a function of age. *Experimental Gerontology*, *110*, 1-8.

Behan, F. P., Maden-Wilkinson, T. M., Pain, M. T., & Folland, J. P. (2018). Sex differences in muscle morphology of the knee flexors and knee extensors. *PLoS One*, *13*(1), e0190903.

Chon, J., Kim, H. S., Lee, J. H., Yoo, S. D., Yun, D. H., Kim, D. H., Lee, S. A., Han, Y. J., Soh, Y., Kim, Y., Han, Y. R., Won, C. W., & Han, S. (2018). Association between asymmetry in knee extension strength and balance in a community-dwelling elderly population: a cross-sectional analysis. *Annals of Rehabilitation Medicine*, *42*(1), 113.

Fang, C., He, B., Wang, Y., Cao, J., & Gao, S. (2020). EMG-centered multisensory based technologies for pattern recognition in rehabilitation: state of the art and challenges. *Biosensors*, *10*(8), 85.

Grote, C., Reinhardt, D., Zhang, M., & Wang, J. (2019). Regulatory mechanisms and clinical manifestations of musculoskeletal aging. *Journal of Orthopaedic Research®*, *37*(7), 1475-1488.

Iamtrakul, P., & Chayphong, S. (2021). Healthy Aging in Home Environment Exposures. *GMSARN International Journal*, *15*, 175-184.

Krishnan, C., & Williams, G. N. (2009). Sex Differences in Quadriceps & Hamstrings EMG-Moment Relationships. *Medicine and science in sports and exercise*, *41*(8), 1652.

LaRoche, D. P., Villa, M. R., Bond, C. W., & Cook, S. B. (2017). Knee extensor power asymmetry is unrelated to functional mobility of older adults. *Experimental gerontology*, *98*, 54-61.

Published online: Copyright © 2016-2022 Rangsit University

Marques, N. R., Hallal, C. Z., Spinoso, D. H., Crozara, L. F., Morcelli, M. H., Karuka, A. H., Navega, M. T., Goncalves, M. (2016). Age-related alterations in the activation of trunk and lower limb muscles during walking. *Journal of Back and Musculoskeletal Rehabilitation*, *29*(2), 295-300.

Matsumoto, H., Hagino, H., Sageshima, H., Osaki, M., Tanishima, S., & Tanimura, C. (2015). Diagnosis of knee osteoarthritis and gait variability increases risk of falling for osteoporotic older adults: The GAINA study. *Osteoporosis and Sarcopenia*, *1*(1), 46-52.

Oshima, Y., Watanabe, N., Iizawa, N., Majima, T., Kawata, M., & Takai, S. (2019). Knee–hip–spine syndrome: improvement in preoperative abnormal posture following total knee arthroplasty. *Advances in Orthopedics*, *2019*, Article ID 8484938. https://doi.org/10.1155/2019/8484938

Papagiannis, G. I., Triantafyllou, A. I., Roumpelakis, I. M., Zampeli, F., Garyfallia Eleni, P., Koulouvaris, P., ... & Babis, G. C. (2019). Methodology of surface electromyography in gait analysis: review of the literature. *Journal of medical engineering & technology*, *43*(1), 59-65.

Phinyomark, A., Phukpattaranont, P., & Limsakul, C. (2012). Feature reduction and selection for EMG signal classification. *Expert systems with applications*, *39*(8), 7420-7431.

Rhon, D. I., Lentz, T. A., & George, S. Z. (2017). Unique contributions of body diagram scores and psychosocial factors to pain intensity and disability in patients with musculoskeletal pain. *Journal of orthopaedic & sports physical therapy*, *47*(2), 88-96.

Smith, S., Rush, J., Glaviano, N. R., Murray, A., Bazett-Jones, D., Bouillon, L., Blackburn, T. & Norte, G. (2021). Sex influences the relationship between hamstrings-to-quadriceps strength imbalance and co activation during walking gait. *Gait & Posture*, *88*, 138-145.

Szpala, A. (2019). Age-related differences in the symmetry of electromyographic activity and muscle force in lower limbs. *Acta of bioengineering and biomechanics*, *21*(4).

Takagi, S., Omori, G., Koga, H., Endo, K., Koga, Y., Nawata, A., & Endo, N. (2018). Quadriceps muscle weakness is related to increased risk of radiographic knee OA but not its progression in both women and men: the Matsudai Knee Osteoarthritis Survey. *Knee Surgery, Sports Traumatology, Arthroscopy*, *26*(9), 2607-2614.

Webster, J. B., & Darter, B. J. (2019). Principles of normal and pathologic gait. In Atlas of Orthoses and Assistive Devices (pp. 49-62). Amsterdam, Netherlands: Elsevier.

Zubiashvili, T., & Zubiashvili, N. (2021). Population aging- a global challenge. *Ecoforum Journal*, *10*(2). Retrieved from http://www.ecoforumjournal.ro/index.php/eco/article/view/1248/754

Published online: Copyright © 2016-2022 Rangsit University